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SUPPLEMENTARY TEST AND EVALUATION REPORT

FJW 120X CAPABILITY FOR THE ZOOM 240 MICROSTEREOSCOPE SYSTEM

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NPIC/R-19/74
JUNE 1974

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Comments and queries regarding this report are welcomed.
They may be directed to [redacted]
NPIC/TSG/ESD/TEB, Code 143, Ext. 3681

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Figure 1. FJW 15X Eyepieces and 2.65X Objectives for the 120X Capability for the Zoom 240 System

FJW 120X CAPABILITY FOR THE ZOOM 240 MICROSTEREOSCOPE SYSTEM

1. INTRODUCTION

The FJW 120X Capability for the Zoom 240 Microstereoscope System consists of 15X eyepieces and 2.65X stereo objectives. This report contains the results of comparative testing between the prototype B&L components and the preproduction FJW components. The prototype B&L 120X Capability for the Zoom 240 System was tested and reported in T&E Report NPIC/R-14/73, October 1973. A supplementary report was published on comparative testing between the B&L and FJW 2.65X objectives. (See T&E Report NPIC/R-07/74, Feb. 74.) The primary consideration for these comparative tests was to determine if the FJW components are as good as the B&L components. With the arrival of four 15X eyepieces on 9 April 1974, the final phase of this test program began. This involved repeating all the previous tests and documenting other characteristics of the Zoom 240 System. Figures 1 and 2 illustrate the FJW components comprising the 120X capability.

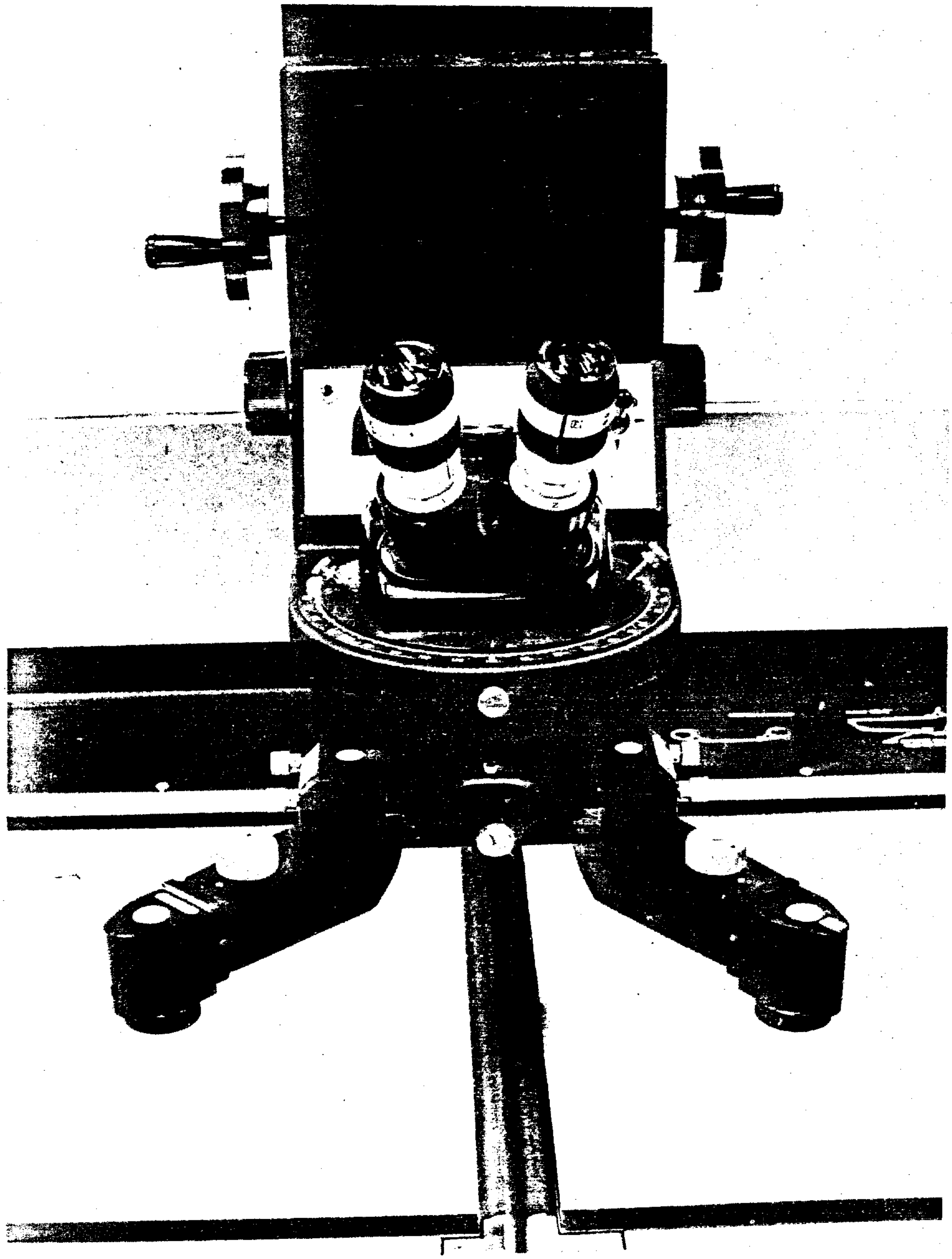

Figure 2. FJW Components Mounted on the B&L Zoom 240 Microstereoscope Pod

2. SUMMARY OF TEST RESULTS

BETWEEN THE FJW AND B&L 120X CAPABILITY

All the following characteristics were measured at maximum magnification with a Zoom 240 and appropriate accessories.

Optical Characteristics	FJW Optics	B&L Optics
Viewing port transmission	7.5 %	3.8 %
System light transmission (using the FJW objective in both cases)	0.86%	0.76%
Spectral characteristics (using the FJW objective in both cases)	slight visual difference	
Eye relief	20 mm	20 mm
Exit pupil diameter	1.0 mm	1.0 mm
Magnification (total)	116.5X	115.3X
Eyepiece magnification	14.9X	14.7X
Distortion (total)	8-9%	8-9%
Field of view (linear)	2.50 mm	2.51 mm
Angular field of view (subtended)	59.7°	59.3°
Eyepiece focal plane diameter	19.7 mm	19.7 mm
Working distance	6.7 mm	6.5 mm
Resolution	465 lp/mm	465 lp/mm
Optical glass quality	Fair	Very Good

The following are characteristics of the Zoom 240 microstereoscope system. The choice of FJW or B&L optics has no effect on these characteristics. These results were included for documentation purposes only.

Zoom 240 Characteristics	FJW or B&L Optics
Line of sight (below horizontal)	59°
Viewing mode/magnification	Stereo to 115X Mono to 90X (w/2X obj)
Convergence angle range*	Approximately 11° - 18°
Interpupillary distance range*	Approximately 56 - 76 mm
Image vibration (120X)	Bothersome vibration with conventional [redacted] bridge. Negligible vibration with ESD steel bridge.
Image rotation	360° in each eyepiece.
Parcentration (Image Run Out)*	Alignment can be adjusted to contain image wander to within 0.23 mm from center in the eyepiece focal plane.
Stereo pair separation	Maximum - 36.6 cm (14.41 in) Minimum - 3.6 cm (1.42 in)
Eyepiece focus range	Greater than +6 diopters in left eyepiece.

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* These characteristics may vary somewhat in each Zoom 240. The convergence angle varies with IPD.

3. CONCLUSIONS

3.1 Comparison Between FJW and B&L

In regard to optical performance, the FJW 120X capability was equal to or better than the B&L 120X capability. The eyepieces, in general, were received quite favorably by the PIs. The most frequent comments were that the wide field of view was very pleasing and the added magnification useful.

The only differences which existed were in the apparent color of the image and the optical glass quality. The FJW eyepiece produced a slightly reddish tint compared to the B&L eyepiece. This difference is small enough to be insignificant for most tasks. The optical glass quality of the FJW eyepiece was judged to be worse that the B&L eyepiece. To determine what effect this would have on photointerpretation, the eyepieces were routed to operating components for evaluation. In general, no one complained about the various cosmetic defects found in the FJW eyepieces.

3.2 Potential Troublesome Areas of the 120X Capability

3.2.1 Vibration

In the first report on the B&L 120X capability (T&E Report NPIC/R-14/73), the Test and Evaluation Branch, ESD/TSG, concluded, in agreement with the operating components, that the 120X capability will be severely limited by vibrations. TEB went on to recommend that solutions to the vibration problems be sought. Tests have shown that the subsequently developed ESD steel bridge beam is expected to reduce the vibration problem to an acceptable level when used in combination with these 120X optics. However, efforts in this area should continue in connection with future higher magnification developments.

3.2.2 Focus Mechanism

Also in the first report, TEB had recommended that the focus mechanism of the [redacted] light tables, as originally provided, be improved before providing the PIs with the 120X

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capability. Modifications to all of the original focus mechanisms have been made. However, the effectiveness of the modified focus mechanism is currently being compared to the old focus mechanism and a new Richards microscope mount. As yet, no conclusions are available.

3.2.3 Parcentration (Image Run Out)

If the 120X capability is to be used in a monoscopic mode, a potential problem may exist in vertical misalignment between the optical trains. As discussed in Section 4.18, under worst case conditions, a vertical angular misalignment up to 1.5 degrees is possible with the 15X eyepieces. With the 10X eyepieces, the same sources of misalignment produces an error of 1 degree. Experimental data indicates that a 1-degree vertical angular misalignment is about the largest permissible for binocular fusion to occur. Tighter tolerances for image run out can reduce the amount of misalignment error. The Equipment Performance Branch, ESD/TSG, which handles the alignment for the Zoom 240, has been contacted on this and can help if anyone has problems with binocular fusion using the new 15X eyepieces.

4. TEST RESULTS

The following tests were made with a B&L Zoom 240 pod (#172 BF), B&L rhomboid arm (#102TZ), FJW 15X eyepiece (#001), and FJW 2.65X stereo objective (#A). The measurements were then repeated with the B&L 15X eyepiece (#53999486) and B&L 2.65X stereo objective (#53999467) for comparison. In some cases the tests were designed to check differences in the eyepieces only. In those situations, the only difference in the setup was the replacement of the eyepiece. The FJW 2.65X objective was used in both cases. In this manner, the setups were identical except for the eyepieces. These tests are identified by the following phrase: "using the FJW objective in both cases."

4.1 Viewing Port Transmission

Measurements were taken with the Spectra Spot Brightness meter and a +3 diopter lens for closeup work. The viewing port transmission of the B&L objective was measured to be 3.8 percent, while the FJW viewing port transmission produced an average transmission of 7.5 percent over six objectives. The range of transmission for the FJW objective viewing ports was from 6.6 percent to 9.4 percent.

4.2 System Light Transmission (using the FJW objective in both cases)

System transmission was measured with the UDT-11A photometer and microscope sensor head. The sensor was positioned 20 mm away from the top surface of the eyepiece. Luminance measured 23 fL using the FJW eyepiece and 21 fL using the B&L eyepiece. The source measured 2730 fL using the UDT photometer. The transmission (visual) was then calculated to be 0.86 percent for the FJW setup and 0.76 percent with the B&L eyepiece and FJW objective setup.

4.3 Spectral Characteristics (using FJW objective in both cases)

Spectral characteristics were measured with a Gamma 3000 spectroradiometer. Figure 3 shows the normalized spectral

NORMALIZED RELATIVE SPECTRAL TRANSMISSION Of: The FJW and B&L 120X Capability for the Zoom 240

DATE: 12 April 1974 BY: G.N.

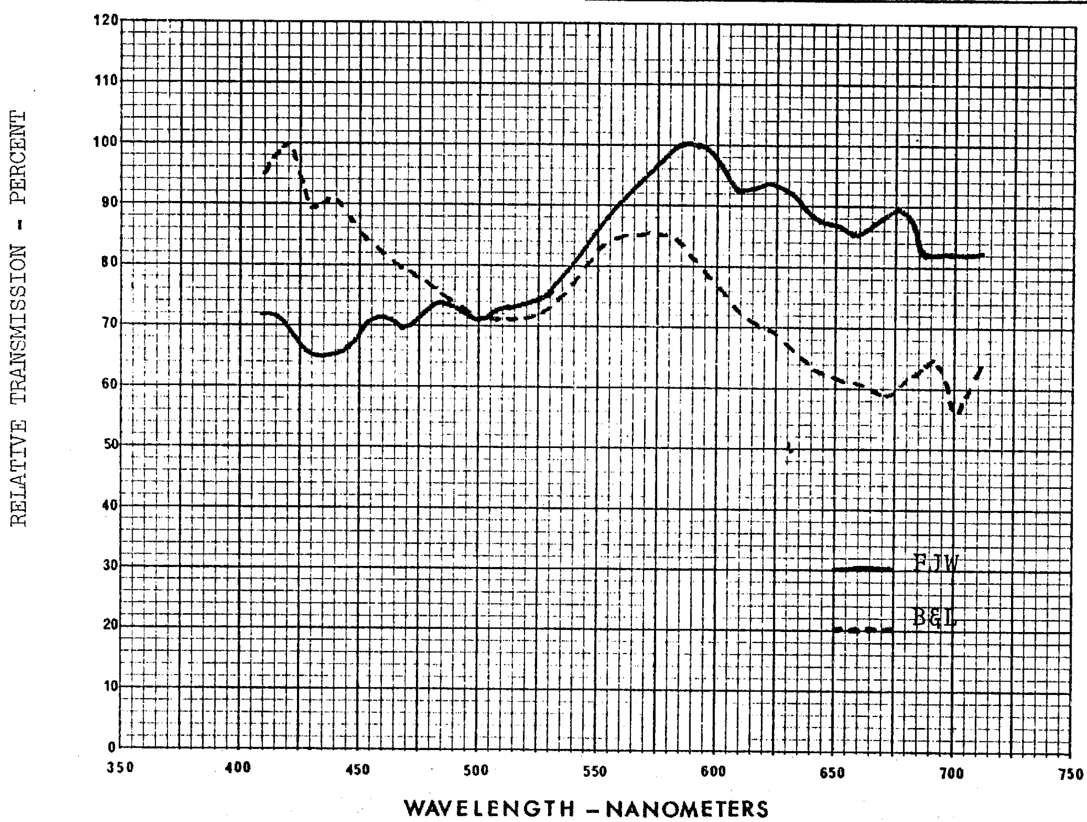

Figure 3

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transmission of the FJW setup and the B&L eyepiece and FJW objective setup. The differences in the curves are due only to the eyepieces since all else was kept constant.

The color temperature of the [redacted] 1540-4 (Ser. #013) light table measured 4930 degrees K. Color properties of the light coming through the optics were also measured. The apparent color temperature with the FJW eyepiece and objective is 4150 degrees K while with the B&L eyepiece and FJW objective combination, it measured 4970 degrees K. The apparent color temperature difference of 820 degrees K is again due to the differences in the eyepieces. The spectral distribution of the light coming through the optics is illustrated in Figure 4. STATINTL

4.4 Eye Relief

Eye relief was measured with a vernier caliper and a piece of ground glass mounted on it. Both the B&L and FJW setup produced an eye relief of 20 mm at 115X magnification.

4.5 Exit Pupil Diameter

Exit pupil diameter was measured with a metric scale inscribed on a ground glass screen. The exit pupil diameter measured 1.0 mm at 115X with both B&L and FJW eyepieces.

4.6 Magnification

Total magnification was measured using a theodolite with a diopter telescope mounted on it. Measurements were made at the maximum magnification setting. Since the focus on the objective can affect magnification, the measurements were done with the focus knob turned all the way in. This condition provides the highest magnification. The focus knob on the rhomboid arm was set at center of travel. Maximum magnification of the FJW setup measured 116.5X while the B&L setup measured 115.3X.

Eyepiece magnification was computed after measuring the combined zoom and objective magnification with a reticle in the eyepiece focal plane and an appropriate target in the film plane. The zoom and objective magnification was divided into the total magnification to obtain the eyepiece magnification. The FJW eyepiece measured 14.9X while the B&L eyepiece measured 14.7X.

NORMALIZED RELATIVE SPECTRAL RESPONSE OF: Light energy coming through the FJW and B&L 120X capability

DATE: 12 April 1974 **BY:** G.N.

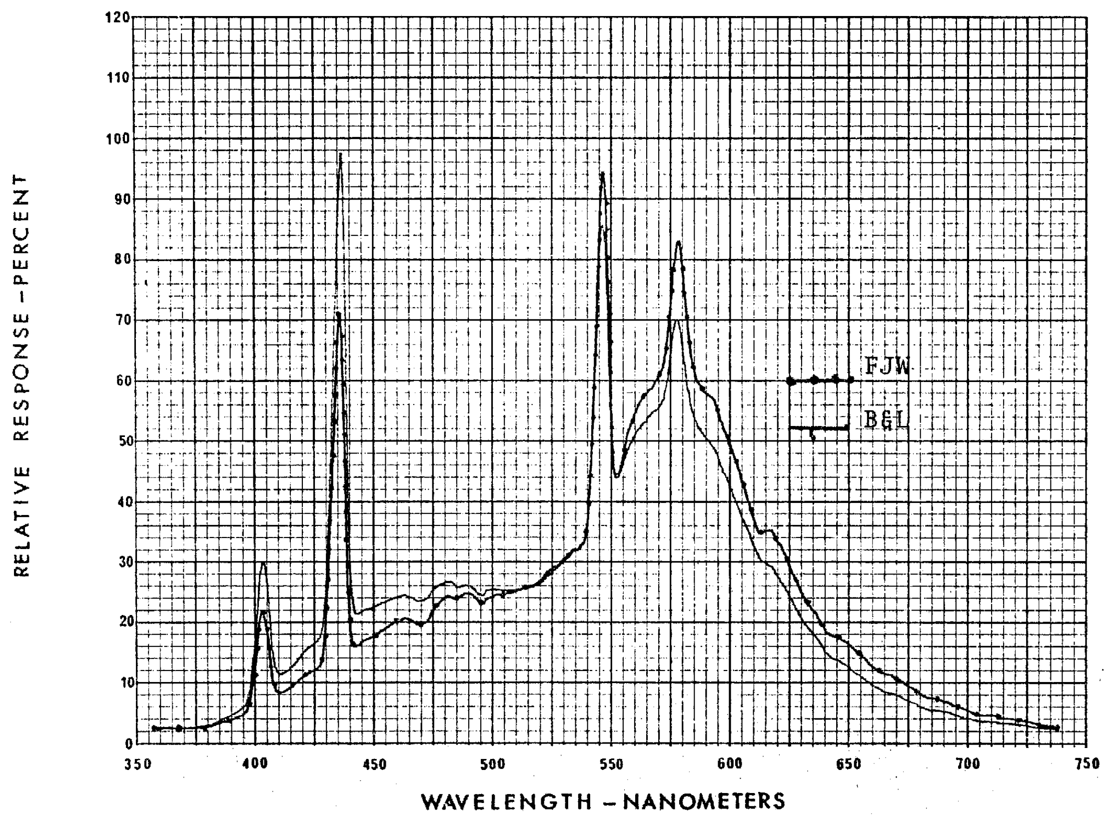

Figure 4

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4.7 Distortion

The setup used for total magnification was also used to measure distortion. The total system distortion for both the FJW setup and B&L setup measured between 8 and 9 percent at approximately 80 percent of the field and at 115X magnification.

4.8 Field of View

The linear field of view was measured at 115X magnification with a Maxta reticle scale with 0.1 mm increments. The diameter of the field of view for the FJW setup was 2.50 mm while the diameter of the B&L setup was 2.51 mm.

The angular field of view was computed from the magnification and linear field of view by means of the following formula:

$$\theta = 2.0 \arctan \left(\frac{DM}{508}\right)$$

where θ = angular field of view in degrees

D = diameter of field of view in millimeters

M = total system magnification.

The angular field of view for the FJW setup was 59.7 degrees and for the B&L setup it was 59.3 degrees.

4.9 Eyepiece Focal Plane Diameter

The eyepiece focal plane diameter was calculated from the eyepiece magnification and angular field using the following equation:

$$EFPD = \frac{508. \tan (\theta/2)}{EPM}$$

where EFPD = eyepiece focal plane diameter in millimeters

θ = angular field of view in degrees

EPM = eyepiece magnification

The eyepiece focal plane diameter for both the FJW and B&L eyepiece was 19.7 mm.

4.10 Working Distance

A vernier caliper was used to make working distance measurements. The FJW setup provided a working distance of 6.7 mm at 115X magnification. The working distance for the B&L setup measured 6.5 mm. The difference between the two is within measurement error.

4.11 Resolution

Resolution was measured at two magnifications using three observers. TEB Resolution Target #83 was used in this test. At 28X the resolution was 161 lp/mm for both setups. At 115X the results were also the same at 456 lp/mm. These are median values of the three observers. A cursory examination of the off-axis resolution detected no significant differences between the B&L and FJW setups.

4.12 Optical Glass Quality

Examination of optical glass quality refers to inspecting for cosmetic defects such as air bubbles, striae, digs, and scratches in or on the glass elements. In some cases, surface scratches were objectively measured with a traveling stage microscope to determine the scratch width and length. The following subjective evaluation of bubbles and scratches was determined using the B&L eyepiece as a basis for comparison:

Eyepiece	Subjective Comment
B&L No. 53999486	Very Good
FJW No. 001 (#A)	Good
FJW No. 002	Fair
FJW No. 003	Poor
FJW No. 004	Fair

In regards to bubbles and scratches, the FJW eyepiece was judged to be of lower quality than the B&L eyepieces.

To determine whether or not these cosmetic defects would be a source of annoyance in operational use, the four eyepieces were routed to four P.I. components for evaluation. All comments received indicated that these defects were not obvious, were not objectionable, and would not significantly affect their use on light tables. When the eyepieces were used on comparators with condenser light sources, however, the scratch marks, dirt, etc., did become obvious and objectionable, but no more so than with currently available eyepieces.

Note: The following are characteristics of the B&L Zoom 240 microstereoscope system. The choice of FJW or B&L optics has no effects on these characteristics. These results were included for documentation purposes only.

4.13 Line of Sight

The line of sight for the B&L Zoom 240 system is 59 degrees below the horizontal. According to the Boeing Human Factors Design Guide, the observer's line of sight should be between 15 to 40 degrees below the horizontal, with 30 degrees the preferred value. "As an individual is forced to direct his gaze to a greater angle, discomfort may occur.... Lowering it too far can lead to increased muscle fatigue due to the need to support the head while it is tilted forward."*

4.14 Viewing Mode

Presently, the 120X capability provides only a stereo viewing mode. A 2.65X mono objective is under development. It is possible to use the currently available 2.0X mono objective with the 15X eyepieces to provide up to 90X magnification in the monoscopic mode. The process of changing from stereo to 90X mono does not usually require that any components be removed or added if the focus knob on the stereo objective is turned in to clear the table during mono use.

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* Boeing Document #DK-702, Advanced Viewing Systems Design Criteria, p. 33.

4.15 Convergence Angle/Interpupillary Distance

Since there is a definite relationship between the convergence angle and interpupillary distance, the data was combined and graphically illustrated in Figure 5. The Zoom 240 that was used in this case had the smaller diameter eyepiece tubes. Approximately 50 percent of the Zoom 240 microstereoscopes have the larger eyepiece tubes which limit the minimum IPD to approximately 60 mm. Although measurements were not made on the microstereoscopes with the larger eyepiece tubes, a similar relationship between convergence angle and IPD is presumed to exist. The numbers given above and illustrated by the graph in Figure 5 are considered typical. Differences in IPD and convergence angle may exist within the same model of microstereoscopes due to slight mechanical differences.

4.16 Image Vibration

Subjective measurements of vibration were made using the Foeppel vibration graticule on the Zoom 240 with a standard STATINTL [redacted] 1540 light table [redacted] Figure 6 illustrates the vibration characteristics. STATINTL "Air compressors" refer to a periodic source of vibration caused by two Worthington Corporation air STATINTL compressors that are bolted to the concrete floor at the northwest corner of [redacted] These compressors supply air to STATINTL [redacted] and they alternately cycle on and off continuously throughout normal working hours. Preliminary investigations indicate that their effect is restricted to the north end of STATINTL [redacted]

With the ESD steel bridge beam, all bothersome signs of vibration disappeared at magnifications up to 120X. Figure 7 illustrates the vibration characteristics with this bridge. For further details on the vibration aspects, see TEB Report NPIC/R-08/74.

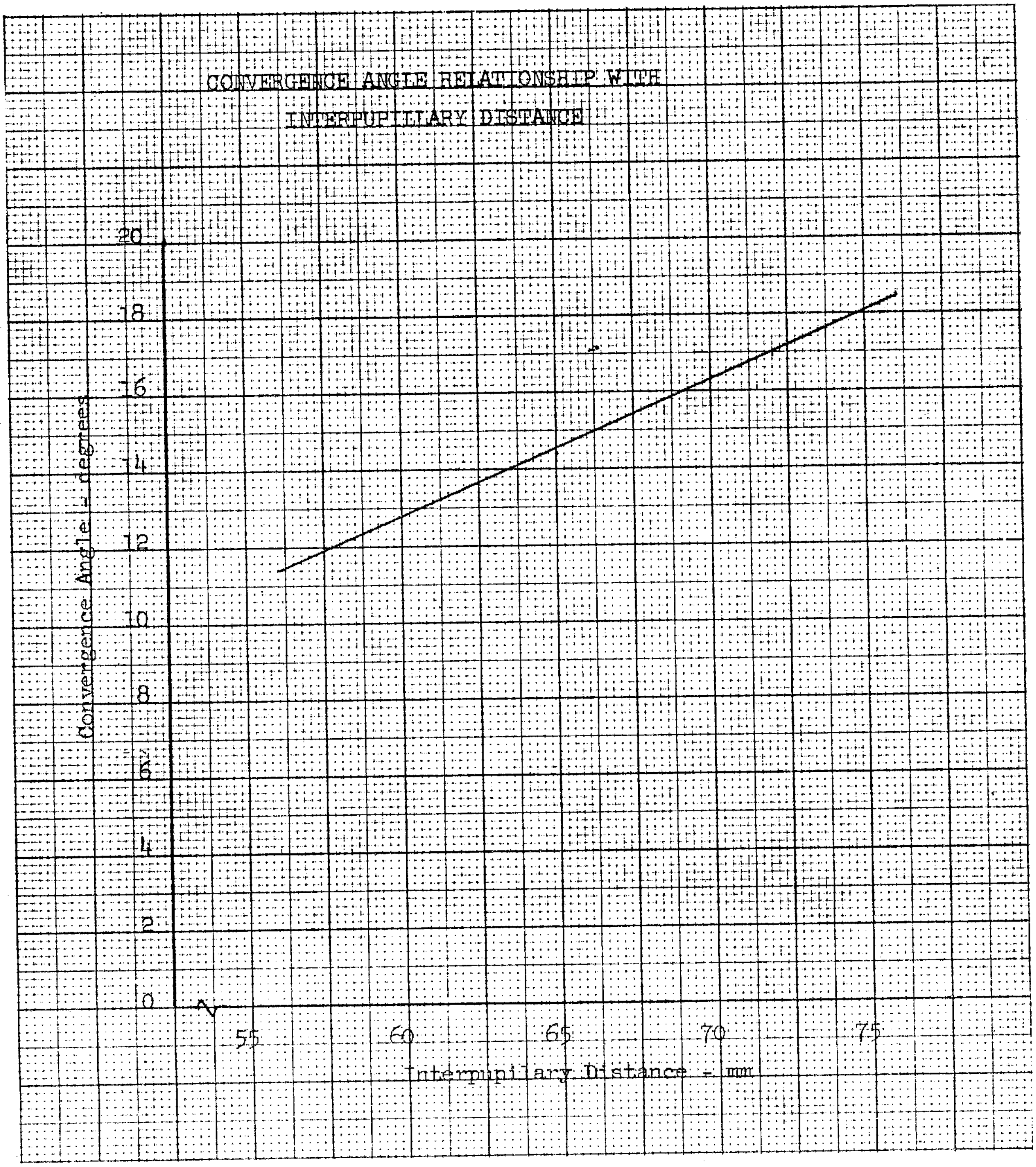
CONVERGENCE ANGLE RELATIONSHIP WITH
INTERPUPILLARY DISTANCE
Convergence Angle - degrees
20
18
16
14
12
10
8
6
4
2
0
55
60
65
70
75
Interpupillary Distance - mm

Figure 5

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Visual Image Vibration
ESD Steel Beam Light Table, Serial No. 221*

Legend	
X	Test condition implemented
	No vibration
	Barely detectable vibration
	Bothersome vibration

Barry SLM-6 (rear)	Barry SLM-6 (front)	Pneumatic tires (rear)	Pneumatic tires (front)	Hard rubber tires (rear)	Hard rubber tires (front)	Table tilted	Air compressor (on)		Magnification 28X	40X	60X	80X	100X	120X
X	X					X	X	1						
X	X						X	2						
X	X					X		3						
X	X							4						
X					X	X	X	5						
X					X		X	6						
X					X	X		7						
X					X			8						
				X	X	X	X	9						
				X	X		X	10						
				X	X	X		11						
				X	X			12						
		X	X			X	X	13						
		X	X				X	14						
		X	X			X		15						
		X	X					16						
X			X			X	X	17						
X			X			X		18						

* Data taken from T&E Report NPIC/R-08/74.

Figure 7

4.17 Image Rotation

Almost all in-house Zoom 240 pods have 360 degree image rotation in both eyepieces. Approximately 50 percent of these will have image rotation locks on them. The other 50 percent have such a large diameter eyepiece tube that installing image rotation locks on them would make the minimum IPD too large for many people to use comfortably.

4.18 Parcentration (Image Run Out)

Measurements of image run out were not made. The following information was obtained from EPB as representing "typical" errors for image run out from the on-axis position as a function of image rotation, zoom, and objective adjustments.

Distance in Millimeters from On-Axis in the Eyepiece Focal Plane

Image Run Out Error	Component
.10	Image rotation
.08	Zoom
.05	Objectives (within pod)
.23	Total

At 15X eyepiece magnification, a vertical displacement of the image from the on-axis position of 0.23 mm in the eyepiece focal plane corresponds to a vertical angular misalignment of 0.75 degrees. Under worst case conditions, assuming the angular misalignment to exist in both eyepieces, the total misalignment would be twice that amount or 1.5 degrees. The Boeing Human Factors Design Guide permits a maximum vertical misalignment of approximately 1 degree for short term binocular fusion. With the conventional B&L 10X W.F. eyepieces, the vertical angular misalignment was approximagely 1 degree under worst case conditions. The above discussion pertains only to the monoscopic mode of operation, not the stereo. In the stereo mode, the misalignment can be corrected by carefully positioning one of the stereo pairs for proper fusion.

4.19 Optical Path Separation

The maximum separation using the rhomboid arms and 2.65X objectives measured 36.6 cm (14.41 in.). The minimum separation measured 3.6 cm (1.42 in.) with the mono objective removed. With the mono objective in place, the minimum stereo separation was 3.9 cm (1.54 in.).

4.20 Eyepiece Acuity Adjustment Range

The eyepiece acuity adjustment range for the B&L Zoom 240 microstereoscope was calculated from the eyepiece magnification and eyepiece displacement (on the adjustable eyepiece). Complete details of the procedure can be found in the Optical Testing Procedures Manual by Data Corporation (Focus Test No. 4). The range of adjustment was computed to be greater than ± 6 diopters from the position of parfocalization between the optical trains.

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